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A Multifactorial Approach to Understanding Fall Risk in Older People

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ABSTRACT

OBJECTIVE:

To identify the interrelationships and discriminatory value of a broad range of objectively measured explanatory risk factors for falls.

DESIGN:

Prospective cohort study with 12-month follow-up period.

SETTING:

Community sample.

PARTICIPANTS:

Five hundred community-dwelling people aged 70 to 90.

MEASUREMENTS:

All participants underwent assessments on medical, disability, physical, cognitive, and psychological measures. Fallers were defined as people who had at least one injurious fall or at least two noninjurious falls during a 12-month follow-up period.

RESULTS:

Univariate regression analyses identified the following fall risk factors: disability, poor performance on physical tests, depressive symptoms, poor executive function, concern about falling, and previous falls. Classification and regression tree analysis revealed that balance-related impairments were critical predictors of falls. In those with good balance, disability and exercise levels influenced future fall risk—people in the lowest and the highest exercise tertiles were at greater risk. In those with impaired balance, different risk factors predicted greater fall risk—poor executive function, poor dynamic balance, and low exercise levels. Absolute risks for falls ranged from 11% in those with no risk factors to 54% in the highest-risk group.

CONCLUSIONS:

A classification and regression tree approach highlighted interrelationships and discriminatory value of important explanatory fall risk factors. The information may prove useful in clinical settings to assist in tailoring interventions to maximize the potential benefit of falls prevention strategies.

Introduction

Research aimed at understanding the causes of falls in older people now dates back 50 years. In his pioneering 1960 study, Sheldon attempted to systematically classify falls into particular subtypes and to elucidate the role that discrete diseases and impairments in postural stability play in predisposing older people to fall.[1] Much of Sheldon's work has been confirmed in subsequent studies using robust epidemiological designs conducted in the late 1980s and beyond. As outlined in a recent review, impaired balance, poor muscle strength, visual impairment, psychoactive and multiple drug use, impaired gait, depression, dizziness, activity of daily living (ADL) limitations, arthritis, diabetes mellitus, pain, impaired cognition, and urinary incontinence have consistently been found to increase the risk of falls individually and cumulatively.[2]

Determining the relative contributions of preexisting diseases to risk of falling enables clinicians to determine appropriate medical interventions, but attributing a degree of falls risk to a specific medical diagnosis is problematic because the severity of conditions varies considerably between individuals. Furthermore, declines in sensorimotor function due to age, inactivity, medication use, or minor pathology may be evident in older people with no documented medical illness. Previous studies have taken a physiological impairment rather than a disease-oriented approach to evaluating falls risk factors to address this issue.[3] This approach has included the development of simple tests of sensory and motor systems that measure aspects of vision, peripheral sensation, muscle strength, reaction time, and postural stability.[3] In studies undertaken in community settings, weighted contributions from these measures can discriminate between older fallers and nonfallers with an accuracy of up to 75%.[3]

Although this is encouraging, including only variables from the physiological domain supporting “static balance” and the use of traditional multivariate statistical techniques that do not allow for estimating fall risk within sample subgroups, as is possible with classification and regression tree (CRT) analysis, limits this approach. Two previous studies have used CRTs for examining fall risk but have included a mix of “marker” and “explanatory” measures as independent variables.[4,5] In particular, these studies have included previous falls as a variable in their models. The inclusion of this strong marker variable as a first discriminator has precluded the inclusion of important explanatory variables and resulted in models that are of limited value in understanding why falls occur.

The aim of this study was to use CRT analysis to identify the interrelationships between and the discriminatory value of a broad range of objectively measured explanatory risk factors for falls in a large sample of community-living older people. A CRT analysis was chosen because it can calculate absolute risk of falls in subgroups within the sample, each with its own set of risk factors and cut-points, which may assist in better-targeted intervention strategies.

METHODS

Participants

Five hundred people aged 70 to 90 participated in the prospective cohort study with a 1-year follow-up for falls. Participants were randomly recruited from a cohort of 1,037 community-dwelling men and women living in eastern Sydney and participating in the first stage of the Sydney Memory and Ageing Study (MAS, January 2006 to October

2007) (study in progress, see acknowledgements). Exclusion criteria of the present study were neurological, cardiovascular, or major musculoskeletal impairments (determined at a baseline assessment) that precluded participants walking 20λm without a walking aid, and cognitive impairment determined by a score of less than 24 on the Mini-Mental State Examination. Approval for the study was obtained from the University of New South Wales Human Studies Ethics Committee.

Measures

At baseline, all participants underwent an extensive assessment of physical, cognitive and psychological measures by trained research assistants. A complete medical history was recorded during a face-to-face interview including the presence of medical conditions, medication use, and falls history. As a measure of comorbidity, the presence of each medical condition was given 1 point from a list of nine system-related conditions (cardiovascular, respiratory, musculoskeletal, endocrine, urogenital, cancer, neurological, mental health, and eye diseases).

Physical Assessment

The Physiological Profile Assessment (PPA)[3] was used to assess five parameters of physiological performance as an estimate of physiological fall risk: visual contrast sensitivity (assessed using the Melbourne Edge Test), proprioception (measured using a lower limb-matching task, with errors in degrees recorded using a protractor inscribed on a vertical clear acrylic sheet placed between the legs), quadriceps strength (measured isometrically in the dominant leg with participants seated with the hip and knee flexed

90º), simple reaction time (measured using a light as stimulus and a finger-press as response), and postural sway (path length, measured using a sway meter recording displacements of the body at the level of the pelvis with participants standing on a foam rubber mat with eyes open). In addition, the coordinated stability test assessed participants' ability to adjust body position in a steady and coordinated way while placing them at or near the limits of their base of support.[6] One-leg balance was added as a simple clinical measure, with total time (maximum of 10 seconds) being recorded that the participant could stand on one leg. Gait was measured as the time (in seconds) needed to walk 3λm, turn and walk back at normal pace.

Cognitive Assessment

Cognitive motor speed and task switching ability, aspects of executive function, were measured using the Trail Making Test (TMT). Part A requires participants to draw lines connecting numbers (e.g., 1-2-3), and Part B requires participants to draw lines connecting alternating letters and numbers (e.g., 1-A-2-B). The difference between the two parts was calculated to remove the speed element from the test evaluation.[7] Language skills were assessed using the Boston Naming test, a visual picture naming task in which 30 outline drawings of objects and animals are presented.[8] Memory performance was assessed using the Logical Memory subtest (Story A) from the Wechsler Memory Scale, in which participants had to recall a story immediately after it was read to them.[9] Visuoconstructional ability was assessed using the Block Design subtest from the Wechsler Adult Intelligence Scale—Revised, with the participant required to arrange blocks according to a pattern as fast as possible.[10]

Psychological Assessment

Concern about falling during 16 ADLs was assessed using the Falls Efficacy Scale International (range 16–64).[11] Symptoms of depression were assessed using the self-reported 15-item Geriatric Depression Scale (range 0–15, scores ≥5 indicating possible depression).[12] Symptoms of anxiety in the past month were assessed using the nine-item Goldberg Anxiety Scale (range 0–9, scores ≥5 indicating possible anxiety).[13] Positive affect was assessed using a subscale of the Positive and Negative Affect Scale (range 10–50).[14] Personality was assessed using three subdomains of the self-reported NEO Personality Inventory: neuroticism, openness, and conscientiousness.[15]

Disability, Physical Activity, and Quality-of-Life Assessment

Levels of disability were assessed using the 12-item World Health Organization Disability Assessment Schedule (WHODAS II, total score range 0–36). Quality of life was assessed using the 20-item Assessment of Quality of Life (AQoL) II (range 0–100).[16] A new stringent disability score was computed using Rasch modelling.[17] This score was devised to identify people with low levels of disability. Five questions were selected from both questionnaires (AQoL items 2 and 15, WHODAS items 3, 6, and 8) assessing disability in five different areas: mobility on three levels (activities at home, activities outside home, walking), mental functioning, and pain (Figure 1). The five-item disability scale had good internal consistency, with a Cronbach alpha of 0.78. Detailed information on frequency and duration of physical activity was assessed using the Incidental and Planned Activity Questionnaire.[18]

Falls Follow-Up

A fall was defined as "an unexpected event in which the person comes to rest on the ground, floor, or lower level."[19] Fall frequency during the 1-year follow-up was monitored with monthly falls diaries and follow-up telephone calls as required.[19] Participants were also asked whether they suffered any injuries as a result of the fall, such as bruises, lacerations, or fractures. Previous studies have found that that single fallers are more similar to nonfallers than to recurrent fallers on a range of medical, physical, and psychological risk factors.[20–22] In this study, people who suffered a fall with injury and people who suffered multiple falls during the 12-month follow-up period were classified as "significant" fallers because it was decided that single fallers should not be categorized as nonfallers when an injury occurred.

Statistical Analyses

Logistic regression was used to calculate univariate odds ratios for the associations between demographic, physical, cognitive, and psychological measures and significant falls. In subsequent analyses, the best set of significant explanatory risk factors for significant falls was sought using CRT analysis.[23] CRT analysis is a nonparametric technique that can calculate absolute risk of falls in subgroups within a sample, each with its own set of risk factors and cut-points. The analysis starts with the entire cohort and sequentially divides it into subgroups, creating a tree model. The best discriminating variable is selected first and provides the first partition. After this, the remaining variables are examined to determine whether they can provide further discrimination, and this process continues until no further significant discrimination (partitioning) is possible. CRT analysis splits a continuous variable into two groups based on an exhaustive search aiming to find the split (including nonlinear splits) producing the largest improvement in goodness of fit. The CRT model was also undertaken, with multiple falls as the outcome to provide consistency with previous research. The data were analysed using SPSS.17 for Windows (SPSS, Inc., Chicago, IL).

RESULTS

The mean age of participants was 77.9±4.6; 270 (54.0%) participants were female. On self-rated health status using a five-point scale, 425 (85%) participants rated their health as good, very good, or excellent. Of a possible nine system-related medical conditions, the sample had a mean of 3.1±1.5. One hundred sixty-six (33.2%) participants reported significant falls as defined above. Two hundred fourteen (43.6%) reported one or more falls, of whom 120 (24.0%) reported only one fall and 94 (19.1%) reported two or more falls. Seventy-two of 120 single fallers (60.0%) and 69 of 94 multiple fallers (73.4%) had at least one injurious fall.

Univariate logistic regression analyses showed that the risk of experiencing at least one injurious fall or multiple falls was significantly greater with poorer performance on physical tests, higher levels of disability, more symptoms of depression, poorer executive functioning, higher levels of concern about falling, and previous falls. Table 1 shows the means and standard deviations for each dependent variable, with associated odds ratios and 95% confidence intervals for the falls outcome measure.

Only statistically significant ($P \leq .10$[24]) explanatory variables from the initial logistic regression were entered into the CRT program. Of the 15 variables that were entered into the CRT analysis, the program selected five for the final classification tree (physiological fall risk (PPA), coordinated stability, disability, planned exercise, and executive functioning), and seven subgroups were created (Figure 2).

The model initially split people into those with a high fall risk score and those with a low fall risk score based on physiological performance. One hundred ninety-eight participants (39.6%) fell into the low-risk group. People with a low physiological fall risk score and no reported disability interfering with ADLs had the lowest fall risk, with only 10.9% of this group sustaining a significant fall in the follow-up period. Risk was greater in those with a low physiological fall risk score when there was reported disability (30.8%) and greater still in those with reported disability doing no planned physical activity or 4 or more hours of planned physical activity per week (36.8%).

People with a high physiological fall risk score, impaired executive functioning, and poor dynamic balance and who did not participate in any regular planned exercise had the highest fall risk (absolute risk 54.4%). Those with a high physiological fall risk and performed well on one of the additional tests had intermediate levels of fall risk (28.2–41.4%).

The CRT model with multiple falls was similar to the model derived for significant falls (data not shown), with a lowest absolute risk of 7.4% and a highest absolute risk of 25.6%. Planned exercise did not meet the inclusion criteria, probably because of low power as a result of fewer multiple faller cases.

DISCUSSION

By using a CRT tree, risk factors were identified for falls on three different levels. Impairment in balance-related physiological systems, as assessed with the PPA, was selected as the first partitioning variable. Consistent with past research, this indicates that physiological factors such as impaired vision, slow reaction time, and greater postural sway are important contributors to fall risk.[3,21] Additional and different factors were identified in explaining fall risk in older people with low and high physiological risk of falling.

Two factors emerged as important in understanding why people at low physiological risk fall. The first factor was general disability operationalized by measures of mobility, mental functioning, and pain. According to the model, those with low physiological risk and no disability were the least likely to fall. This group, 11% of the sample, represents the healthiest subgroup of the older population and a group in which a dedicated healthcare falls prevention intervention is unlikely to alter risk significantly. A positive score on the disability scale raised absolute fall risk to 31%, indicating that mobility limitations, depression, and pain increase the risk of falls regardless of physiological performance. Finally, in people with some level of disability, regular exercise had a nonlinear association with falling, with people who did no planned activity or 4 or more hours of planned activity at greater risk of falls (37%, vs 21% in those with intermediate exercise levels). This interesting pattern is in accordance with previous studies that have shown that exercise can significantly decrease[25] and increase the risk of falls.[26] It is possible that those with low activity levels have a greater risk related to disuse, whereas those with high activity levels have greater exposure to fall-risk situations.[26]

In people who were identified as at risk of falls from the physiological measurements, the first additional discriminating factor in the model related to cognitive function as assessed using the Trail-Making Tests (42% for people with this factor vs 28% for those without this factor). Poorer executive function has previously been suggested as a possible risk factor for falls.[27] Executive control processes are mediated in the frontal basal ganglia circuitry[28] and are generally defined as the ability to perform complex, goal-directed, and self-serving behaviors independently. Aging of the frontal cortex can therefore lead to subtle failures of inhibition of motor responses and visual attention,[29] which can potentially lead to falls.[27] Executive dysfunction might also lead to falls through an indirect pathway (through its link with performance of daily activities[30] or depression)[31]. Impaired executive function may lead to difficulties in initiating and safely completing ADLs,[30] which may increase fall risk. Knowledge of impairment in executive function might also influence how an intervention, particularly an exercise intervention, is delivered.

The second additional factor in the model was a measure of coordinated stability, which has been related to falls in previous studies. Whereas the PPA assesses individual sensory and motor systems and contains a measure of standing balance control (postural sway), the coordinated stability test provides a complementary measure of dynamic balance control[6] that is required for daily activities such as reaching, turning, and walking. For people with impaired executive function, absolute risk of falls was 34% for people with good coordinated stability and 47% for those without. The final factor for categorizing people with high physiological fall risk and poor coordinated stability was planned physical activity. For this group, exercise was protective, with no U-shaped relationship.

Those who undertook some planned exercise had a 41% risk of falls, whereas those that did not had a 54% risk.

The model helps in understanding of the underlying factors contributing to falls in older people and suggests that some risk factors have different importance in different subgroups. The model therefore has implications for the design and implementation of fall prevention interventions. Overall, it corroborates the importance of exercise but highlights different strategies for different fall-risk groups. People who are at low risk of falls based on physiological performance should be encouraged to exercise regularly, with a specific focus on balance training,[25] to maintain their low risk. This is especially important in the presence of any disability—due to musculoskeletal, mental health, or other conditions—that affects performance of daily activities. Standard interventions to address remediable aspects of any of these conditions should be part of a multifactorial intervention program (e.g., enhanced pain management).

It is likely that people at high risk of falls based on physiological performance will benefit from an exercise intervention, but consideration should be given to how these people are encouraged to exercise safely and effectively. Group-based exercise may be more appropriate for those who are unlikely to initiate an exercise program. Exercise is the most effective single falls prevention strategy in older people[25] and could also improve cognitive performance.[32] The model suggests that cognitive training should also be considered when designing falls prevention strategies, according to more-recent research findings. Cognitive training can improve everyday function[33] and feelings of self-confidence and could therefore also reduce fall risk.[34] A subset of the high-risk group with adequate executive functioning (28%) would benefit from regular exercise in combination with other standard falls prevention strategies such as environmental and medical interventions.

This study has certain limitations. First, the high prevalence of single fallers might indicate a possible volunteer bias. The sample largely consisted of healthy, community-dwelling older adults who would have been expected to have a low falls rate. The decision to use only recurrent or injurious falls should have solved any concerns about overreporting. Second, no measures of affect were included in the final model. This may be because depressive symptoms are strongly interrelated with factors in the model or because rates of depressive symptoms in volunteers are likely to be lower. Complementary path analysis models may assist in documenting the role of this factor. In addition, the findings need validating in an external sample, and because the sample largely consisted largely of healthy, community-dwelling older adults, the findings may not be generalizable to frail older people with significant cognitive impairment or major mobility problems.

In conclusion, the presented model is derived from a community-dwelling sample of older people and provides clinicians with a more-individualized approach to assessment and intervention for falls. The measures reported are practical and feasible to undertake in the clinical setting and when applied have the potential to deliver a more-streamlined approach to prevention.

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Author Contributions: KD and SL: drafted manuscript. SL, KD, and JC: study objectives and design. KD had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. JH assisted with data acquisition. All authors were involved with interpretation of the data and preparation of manuscript.

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Figure 1.μSimplified disability scale reflecting general health from the World Health Organization Disability Assessment Schedule and Assessment of Quality of Life.

In the last 30 days:

How much difficulty did you have in taking care of your household responsibilities?

None	Mild	Moderate	Severe

How much difficulty did you have to get around by yourself outside your house (e.g. shopping, visiting)?

None	Mild	Moderate	Severe

How much difficulty did you have in walking a long distance such as a kilometre?

None	Mild	Moderate	Severe

How much have you been emotionally affected by your health problems?

None	Mild	Moderate	Severe

How often did you experience serious pain?

Never	<1/wk	3-4x/wk	Mostly

Figure 2. µClassification tree to explain why older people fall.

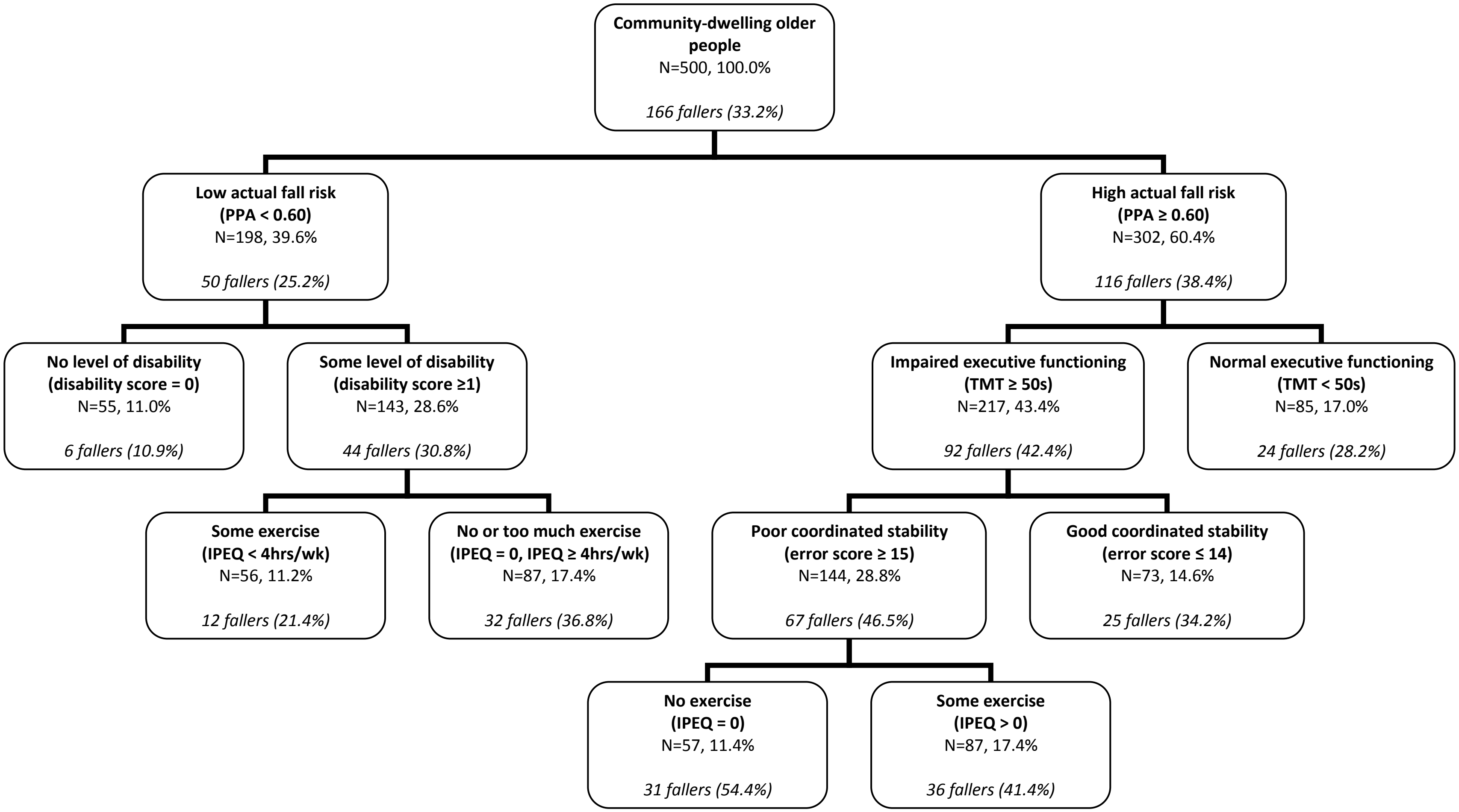

Table 1. Univariate risk factors of experiencing at least one injurious fall or multiple (non injurious) falls during a 12-month follow-up

	Test	Non-fallers (N = 328)			Fallers (N = 166)			OR		95% CI
Medical	Age	77.86	±	4.51	78.23	±	4.76	1.08		0.90 – 1.31
	Gender (female)	175	(52.6%)		92	(55.6%)		1.13		0.77 – 1.65
	Medical conditions	2.98	±	1.57	3.14	±	1.50	1.07		0.95 – 1.21
	Dizziness	122	(38.1%)		76	(47.8%)		1.49	*	1.01 – 2.18
	Arthritis	176	(54.8%)		91	(57.2%)		1.10		0.75 – 1.62
	Diabetes	36	(11.1%)		24	(15.1%)		1.19		0.90 – 1.57
	Total nr of medications	5.15	±	3.36	5.76	±	3.57	1.19	^	0.99 – 1.44
	Psychoactive medications	48	(14.6%)		27	(16.3%)		1.13		0.68 – 1.89
	Concern about falling	21.98	±	6.01	23.97	±	7.04	1.35	**	1.12 – 1.62
	Previous falls (yes)	74	(22.2%)		86	(51.8%)		2.27	**	1.79 – 2.87
Disability	WHODAS	17.70	±	5.93	18.75	±	6.02	1.19	^	0.99 – 1.44
	AQOL-II	90.13	±	8.15	88.54	±	8.52	0.83	^	0.68 – 1.01
	Disability scale	8.57	±	3.41	9.60	±	3.85	1.32	**	1.10 – 1.60
	IPAQ	34.92	±	15.91	32.99	±	16.79	0.89		0.74 – 1.07
Physical	PPA	0.78	±	0.90	1.01	±.	95	1.31	**	1.06 – 1.61
	Coordinated stability	14.56	±	12.57	17.09	±	13.73	1.21	*	1.00 – 1.46
	One-leg balance	7.65	±	3.41	6.87	±	3.65	0.80	*	0.67 – 0.97
	6 m walking test	8.66	±	2.64	9.03	±	3.34	1.14		0.94 – 1.37
Cognitive	Logical memory test	10.97	±	3.87	11.59	±	4.01	1.17	^	0.97 – 1.42
	TMT A	45.10	±	14.97	46.19	±	16.82	1.07		0.89 – 1.29
	TMT B	116.00	±	54.72	123.45	±	53.72	1.16	*	1.01 – 1.33
	TMT B - TMT A	71.09	±	48.27	77.65	±	47.06	2.19	*	1.04 – 4.63
	Boston naming test	24.54	±	3.89	24.74	±	3.68	0.85	^	0.70 – 1.04
	Block design	21.93	±	7.66	22.78	±	8.70	1.05		0.98 – 1.12
Psychological	Geriatric Depression Scale	2.06	±	1.84	2.47	±	2.20	1.22	*	1.01 – 1.47
	Positive affect (PAS)	34.56	±	7.56	34.18	±	6.99	0.95		0.79 – 1.15
	Goldberg Anxiety Scale	0.89	±	1.55	0.99	±	1.64	1.07		0.88 – 1.29
	NEO-FFI	74.77	±	8.17	75.51	±	8.95	1.09		0.88 – 1.35

^ p≤0.10, * p≤0.05, ** p≤0.01